Use of Watershed Characteristics to Select Control Streams for Estimating Effects of Metal Mining Wastes on Extensively Disturbed Streams

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ABSTRACT / Impacts of sediments and heavy metals on the biota of streams in the copper-mining district of southwestern Montana were examined by comparing aquatic communities of impacted streams with those of control streams. Control streams were chosen through the use of a technique that identifies similar streams based on similarities in their watershed characteristics. Significant differences between impacted and control sites existed for surface substrate, riparian vegetation, and the number of macroinvertebrate taxa. These results revealed that: (a) chemical and physical habitats at the impacted sites were disrupted, (b) the presence of trout was an inadequate measure of ecological integrity for these sites, and (c) watershed classification based on a combination of mapped terrestrial characteristics provided a reasonable method to select control sites where potential control sites upstream and downstream were unsuitable.

It is assumed that the quality of a stream site depends on the conditions at the site and in the watershed of that site (Likens and Bormann 1974, Hynes 1975). It is also assumed that the survival of a few trout in a reach, without adequate consideration of what that stream might be like if it were relatively unimpacted, provides an inadequate means to evaluate the ecological integrity of the stream (Warren 1971). Ecological integrity is here defined as the ecological conditions found in relatively unimpacted, typical reaches of typical streams in large, homogeneous, aquatic ecosystem regions (ecoregions). A relatively unimpacted stream was one having its watershed largely vegetated by the mature potential natural vegetation (Kuchler 1964) characteristic of the area, no major point or diffuse sources of pollution, and no major channel modifications. An unimpacted stream site was one with extensive, mature riparian forest, heterogeneous channel morphology and substrate, abundant cover, clear, odorless water, and no local disturbances from roads, livestock, or human refuse. Typical streams and reaches are defined as those draining watersheds that are composed entirely of the predominant land-surface form (Hammond 1964), climate, soil, potential natural vegetation, and land use of that region (Karr and Dudley 1981, Hughes and others 1982).

The impacted streams studied, Prickly Pear Creek and Silver Bow River, are located in southwestern Montana (Figure 1); each stream receives sediments and leachates from tailings of old copper, silver, gold, zinc, and lead mines. Preliminary bioassays by T. Miller (personal communication, USEPA—Las Vegas) had shown that rainbow trout (*Salmo gairdneri*) from both streams had survived concentrations of zinc that exceeded US Environmental Protection Agency criteria (USEPA 1980a and b), implying that those criteria were not suitable at these or comparable sites. However, the relative numbers and biomasses of fish and macroinvertebrate species in Prickly Pear Creek and Silver Bow River had not been compared with those in similar streams that were not impacted by metal mining activities. Also the USEPA's water quality standards regulation (Sabock 1983) requires only that water quality criteria be based on use designations that are consistent with the "protection and propagation of fish, shellfish, and wildlife and recreation in and on the water." There is no requirement for protecting minimum numbers and types of species, nor minimum numbers and biomasses of key or sensitive species. This means that water quality standards designed to protect a sucker fishery or a productive or unproductive trout fishery may satisfy the USEPA equally well, regardless of the potential biota of that stream.

Consequently the objectives of the research herein described were: (a) to demonstrate a watershed classification approach that estimates potential biotic and habitat conditions of a stream site by comparing it with relatively unimpacted sites on other streams that drain watersheds with the same natural characteristics as the impacted stream, and (b) to document changes in fish and aquatic

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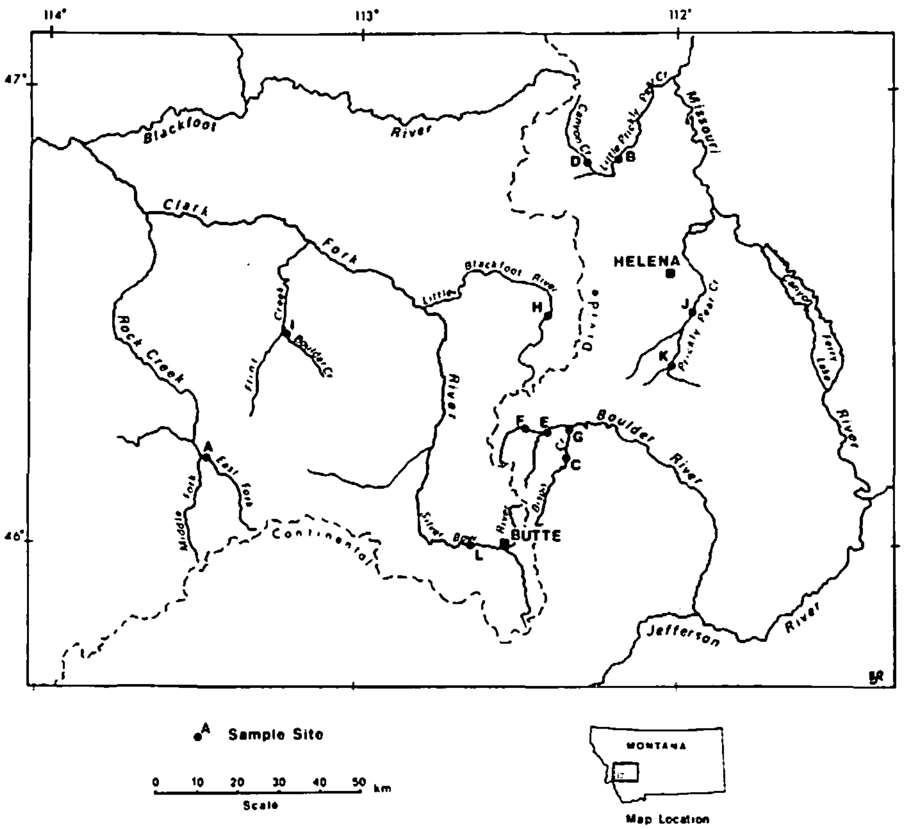

Figure 1. Locations of sampling sites. Sites *A*, *H*, *I*, and *L* are on larger streams west of the continental divide. East of the continental divide, sites *B*, *E*, *G*, and *J* are on larger streams and sites *C*, *D*, *F*, and *K* are on smaller streams. *A*, E. F. Rock Cr.; *B*, L. Prickly Pear Cr.; *C*, Bison Cr.-Shamrock Camp; *D*, Canyon Cr.; *E*, Boulder Cr.-Ladysmith Camp; *F*, Boulder Cr.-Thunderbolt Cr.; *G*, Bison Cr.-Boulder Rv.; *H*, L. Blackfoot Rv.; *I*, Boulder Cr.-Maxville; *J*, Prickly Pear Cr.-Mont. City; *K*, Prickly Pear Cr.-Jeff. City; and *L*, Silverbow Rv.

macroinvertebrate communities associated with metal-mining activities, in spite of the existence of trout at the impacted sites.

This watershed classification approach was based on Warren's (1979) rationale for watershed management and the designs for assessing watershed impacts on small streams of Hall and others (1978). Warren reasoned that the potential biota and their habitats at a stream site could be evaluated by comparing those conditions in several streams that drain watersheds with similar geology, climate, and potentially dominant vegetation. The biota and habitats of the relatively unimpacted streams in a group of streams draining similar watersheds could then serve as empirical models for highly impacted streams. The number of such model streams would depend on the inherent variability of the biota and habitats in streams of the area and on the desired confidence limits. Hall and others stated that there are four basic designs for assessing impacts on small streams (intensive and extensive studies before and after impacts, and intensive and extensive studies after impacts). They found that no design was ideal, but that extensive studies after impacts were most useful. In this study, the extensive postimpact design was chosen because of the historical nature of the problem (James 1980, Wood 1981), the intensive, postimpact toxicological studies already in progress at the sites, and an interest in providing a broader regional perspective for these streams.

Methods

A watershed classification approach was used to select control streams with watershed features comparable to those of Prickly Pear Creek and Silver Bow River. Comparable watersheds were selected by overlaying maps of potential natural vegetation, land-surface form, land use, soil moisture and temperature, and mean annual precipitation. All the watersheds were characterized by flat to rolling grazed grasslands near the streams, changing to low forested mountains with grazed ponderosa pine (*Pinus ponderosa*) at lower elevations and ungrazed Douglas fir (*Pseudotsuga menziesii*) at higher elevations. The soils were classified as cool and moist cryoboralfs and argiborolls (USDA Soil Conservation Service 1967) and the mean annual precipitation ranged from 40 to 50 cm. Because those watershed features were similar to those of Prickly Pear Creek and Silver Bow River, it was assumed that they would provide streams that could be used to estimate the biotic and habitat conditions that existed in Prickly Pear and Silver Bow before their watersheds were extensively mined.

Candidate streams were examined in August 1981 for access, number and size of mines, and stream morphology. A chemically impacted site and a downstream recovery site were selected on Prickly Pear Creek. Two sites similar in watershed area, discharge, and width to the Prickly Pear sites were selected on each of three comparable, but relatively unimpacted, control streams. Because of fall rains and the resulting high flows, only one chemically impacted site on Silver Bow River and a single site on three comparable control streams were sampled. All 12 sites were selected so as to maximize the amount of woody plants along the streams and the substrate and pool size in the streams. Because of diffuse disturbances and incomparable sizes, no control sites could be found upstream of the chemically impacted sites on Prickly Pear Creek and Silver Bow River.

All 12 sites were sampled one time between 22 and 29 September 1981. In each stream, a reach approximately 100 m long containing at least one large pool and riffle was blocked off by nets and the entire area was sampled upstream twice with a battery-powered backpack d.c. electrofisher. The fish caught in each pass were kept separate and the population size of each species was estimated by the method described by Seber and Le Cren (1967). Lengths of all individuals were measured and weights were estimated from length-weight values in Carlander (1969 and 1977) and Finger (1979). Species weight was calculated as the product of mean weight of the catch and N′. The biomass of the fish assemblage equaled the sum of the species weights divided by site area. It is recognized that such estimates based on literature values represent relative weights and biomasses, not actual values. The number of species (s) was recorded and equitability (E′) and diversity (H′) were calculated as $E' = H'/\log_2 s$ and $H' = -\sum_{i=1}^{s} p_i \log_2 p_i$ where p_i equals the proportion of species i in the entire sample. The sites were also compared on the basis of the relative proportions of salmonids and cottids in the fish assemblages.

In the same reach, but before sampling fish, one qualitative macroinvertebrate sample was collected by kicking the riffle substrate in an area of approximately 0.09 m^2 upstream of a 400-μm-mesh kick net for 1 min. The sample was preserved in formalin and later analyzed in the laboratory. The number of taxa, E', and H' were determined as above, except some individuals could only be keyed to genus.

Water samples from each site were passed through a 0.45-μm filter and refrigerated. In the laboratory, total hardness was determined by titration (USEPA 1979) and the levels of Cu and Zn were determined by atomic absorption on graphite and flame spectrophotometers, respectively (USEPA 1979). The geometric mean diameter of the stream substrate was calculated from visual estimates of the percent boulder, cobble, gravel, and sand on the surface of the stream bed, and the amount of woody riparian vegetation immediately along the reach was estimated and noted as percent of reach length as described in Platts (1979). Maximum velocities were measured with a mechanical current meter at the water surface at the heads of riffles. Watershed areas were estimated with a planimeter on 1:24,000 scale US Geological Survey topographic maps, mean annual runoff was estimated from isolines constructed from US Geological Survey data, and mean annual discharges were calculated as the product of runoff and area.

Food quality for macroinvertebrates was estimated from samples of aufwuchs (organisms living on substrates) brushed from four cobbles and suctioned from the bottoms of four shallow pools. This material was returned to the laboratory, centrifuged, freeze dried, passed through a 250-μm sieve, and ground with a mortar and pestle. Three 1-ml aliquots were removed for Kjeldahl digestion of organic N, which was measured on an autoanalyzer and for organic C, which was measured on a CHN autoanalyzer. Values of C and N from the pools and riffles were averaged and a C/N ratio calculated for each site.

Because of the importance of stream size and zoogeographic factors to fish (Gilbert 1980) the small upstream sites, the much larger downstream sites, and the sites on opposite sides of the continental divide were grouped separately. Then a one-tailed t-test was used to test for significantly higher values in environmental and community attributes between the three replicate control sites and the impacted stream in each group.

All 12 sites were examined simultaneously when cluster analysis, principal components analysis, and reciprocal averaging were used to demonstrate the usefulness of the site selection approach for determining comparable sites. A clustering program (Matthews 1981) and an ordination program, ORDIFLEX (Gauch 1977), were employed to compare the similarity and differences among all the sites in the relative composition of their macroinvertebrate genera and fish species com-

Table 1. Estimated density, biomass, and diversity of fish assemblages; numbers were estimated from two passes through a 100-m-long reach.

Set	Stream	No./m^2	g/m^2	No. of species and families	E′ nos.	H′[c]	% Salmonids and cottids[c]
a)	Prickly Pear-Jeff. City[a]	0.2	2.8	2 (2)	1.0	0.30 (1.17)	100 (100)
	Canyon[b]	0.7	9.5	3 (2)	0.46	0.32 (0.45)	100 (100)
	Bison-Shamrock[b]	0.8	16.1	4 (2)	0.45	0.25 (0.49)	100 (100)
	Boulder-Thunderbolt[b]	0.6	17.5	3 (2)	0.67	0.31 (0.44)	100 (100)
b)	Prickly Pear-Mont. City[a]	0.1	12.5	5 (3)	0.73	0.54 (0.41)	78 (22)
	Bison-Boulder Rv.[b]	1.8	25.8	3 (2)	0.27	0.13 (0.33)	100 (100)
	Boulder-Ladysmith Cg.[b]	1.0	19.5	4 (2)	0.50	0.30 (0.55)	100 (100)
	L. Prickly Pear[b]	11.4	43.7	3 (2)	0.13	0.06 (0.40)	100 (100)
c)	Silver Bow[a]	0.0	0.0	0 (0)	0.00	0.00 (0.00)	00 (00)
	Boulder Cr.-Maxville[b]	0.01	0.5	2 (2)	0.80	0.24 (0.24)	100 (100)
	L. Blackfoot[b]	0.5	13.9	5 (2)	0.30	0.21 (0.35)	100 (100)
	East Fork Rock[b]	0.6	15.9	3 (2)	0.40	0.19 (0.41)	100 (100)

[a]Impacted site.

[b]Control site.

[c]Values determined from numbers of individuals and biomass (in parentheses).

bined. Abundance values were normalized by log-transformation because their distribution approached that of a logarithmic series. They were then double standardized by the method of Bray and Curtis (1957) to alleviate scale problems and the qualitative nature of the macroinvertebrate data.

Reciprocal averaging and three options each of principal components analysis and dissimilarity were used; all gave consistent results. These analyses examined the relative location of sites in a taxon space using only the fish species and macroinvertebrate genera common to three or more sites (47% of the taxa). The centered option of principal components analysis and the simple average fusion strategy of the Bray-Curtis dissimilarity measure (Matthews 1981) were chosen for presentation.

Results

The proportion of species relatively intolerant to heavy metals and sediments, such as salmonids and cottids, was higher in the control sites than in Prickly Pear at Montana City, and no fish were collected at Silver Bow River (Table 1 and Appendix 1). No consistent patterns between level of impact and H′ or level of impact and E′ based on fish numbers was shown. However, E′ based on fish biomass was significantly lower ($p < 0.05$) in the impacted sites (Figure 2). Fewer fish species occurred in the impacted sites except for Prickly Pear at Montana City, where two species of suckers were present. The salmonid biomass was significantly higher than the impacted sites ($p < 0.05$) in all the control sites except Boulder Creek at Maxville (Figure 2). Similarly, the total biomass and number of fish were higher in the control sites except for Boulder Creek at Maxville (Table 1)

Macroinvertebrate densities and diversities (Table 2 and Appendix 1) were significantly less ($p < 0.05$) in Prickly Pear Creek at Montana City and in Silver Bow River than at the control sites. However, their densities and diversities at Prickly Pear at Jefferson City and its control sites did not differ significantly. The similarity in diversity (H′) between Prickly Pear at Jefferson City and Bison at Shamrock Camp resulted from the slightly lower equitability (E′) of Bison Creek overriding its much higher number of taxa. The numbers of macroinvertebrate genera and families (Figure 2) were the only consistently significant differences ($p < 0.05$) in the structure of the macroinvertebrate assemblages between impacted and control sites.

The acute (short-duration) toxicity of zinc and the acute and chronic (long-duration) toxicity of copper are functions of total hardness (USEPA 1980 a and b). Only Prickly Pear Creek at Jefferson City and Silver Bow River at Silver Bow contained zinc levels that exceeded national acute criteria (μg Zn/liter = $e^{[0.83(\ln \text{hardness}) + 1.72]}$). Chronic criteria (47 μg Zn/liter) were exceeded at Prickly Pear Creek at Montana City and Bison Creek at Boulder River (Table 3). Copper levels did not exceed national acute criteria (μg Cu/liter = $e^{[0.905 (\ln \text{hardness}) - 1.413]}$), but chronic criteria (μg Cu/liter = $e^{[0.905 (\ln \text{hardness}) - 1.785]}$) were exceeded at Canyon Creek, Bison Creek at Shamrock Camp, and Silver Bow River. The C/N ratios were significantly higher ($p < 0.05$) in Prickly Pear at Montana City and significantly lower ($p < 0.05$) in Silverbow than in their respective control sites, but no significant differences occurred between Prickly

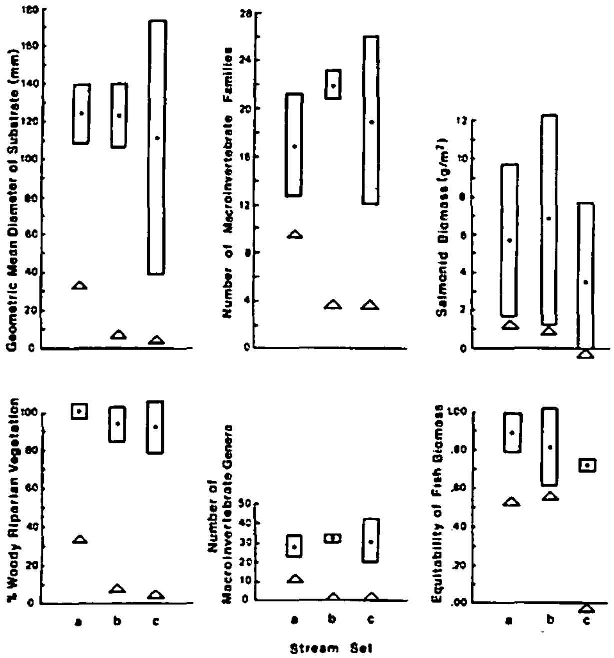

Figure 2. Values at impacted sites, means, and confidence intervals for six measures observed in three sets of four similar streams. Stream sets as in Tables 1-3; values based on one sample per site. *Triangle apices* represent values at impacted sites; *dots* and *bars* represent means and 95% confidence intervals, respectively, at control sites.

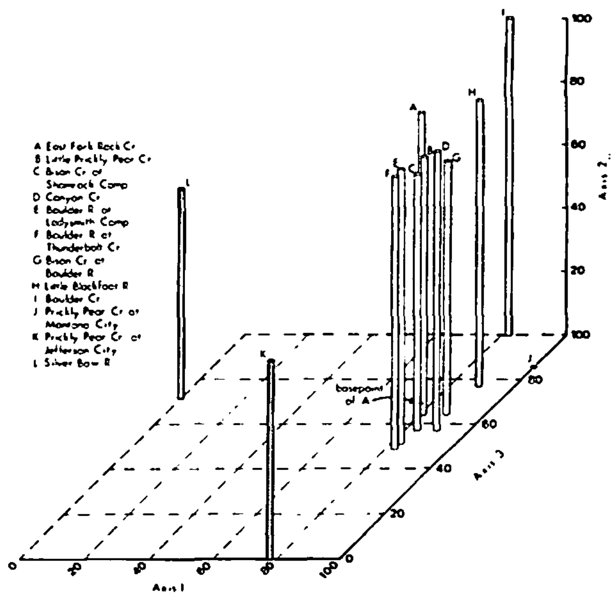

Figure 3. Similarity of samples plotted from their first three principal components. *Site letters* refer to the same sites as in Figure 1. *Shaded sites* (*J*, *K*, and *L*) are the impacted sites. *Axis 1* accounted for 47.5% of the variation and is most strongly associated with increasing proportions of two fish, mottled sculpin (*Cottus bairdi*) and rainbow trout (*Salmo gairdneri*); both species are relatively intolerant of heavy metals and sediment, which were high at Silver Bow. *Axis 2* accounted for 20.5% of the variation and is most strongly associated with increasing proportions of two mayflies (*Ephemerella seratella* and *Rhithrogena*), a case-making caddisfly (*Glossosoma*), and a riffle bettle (*Heterlimnius*); all four taxa are most commonly found on cobbles or gravel, which were limited at Montana City. *Axis 3* accounted for only 7.5% of the variation and is associated with decreasing proportions of brook trout (*Salvelinus fontinalis*) and a net-spinning caddisfly (*Arctopsychae*).

Table 2. Total number of individuals and diversity of macroinvertebrate assemblages; numbers were estimated from one kick net sample in an area of 0.09 m^2.

Stream	No./m^2	E'	H'
a) Prickly Pear-Jeff. City[a]	176	0.72	1.90
Canyon[b]	403	0.76	2.65
Bison-Shamrock Camp[b]	162	0.50	1.62
Boulder-Thunderbolt[b]	205	0.67	2.24
b) Prickly Pear-Mont. City[a]	11	0.85	1.17
Bison-Boulder Rv.[b]	353	0.81	2.82
Boulder-Ladysmith Camp[b]	436	0.77	2.72
L. Prickly Pear[b]	1430	0.74	2.56
c) Silver Bow[a]	20	0.43	0.59
Boulder Cr.-Maxville[b]	268	0.85	2.84
L. Blackfoot[b]	192	0.75	2.43
East Fork Rock[b]	1212	0.39	1.45

[a]Impacted site.
[b]Control site.

Pear at Jefferson City and its control sites. Significant differences ($p < 0.05$) in substrate size and woody riparian vegetation existed among the three impacted sites and their control sites (Figure 2).

The similarities and differences in the fish and macroinvertebrate assemblages are depicted by principal component axes 1, 2, and 3 in Figure 3. All the control sites but Boulder Creek at Maxville (I) grouped fairly closely together on all three axes. However, the Silver Bow River (L) and both Prickly Pear Creek sites (J and K) differed considerably from the control sites along axis 1, 2, and 3, respectively. Comparable dissimilarity between control and impacted streams is demonstrated by the cluster analysis (Figure 4). The larger streams (East Fork Rock Creek, Little Blackfoot River, and Boulder Creek) show increasing dissimilarity from the other control sites, but no more than that between the chemically impacted and recovery sites on Prickly Pear Creek.

Discussion

Single samples from the streams studied, though limited in reliability, are thought to be valid assessments

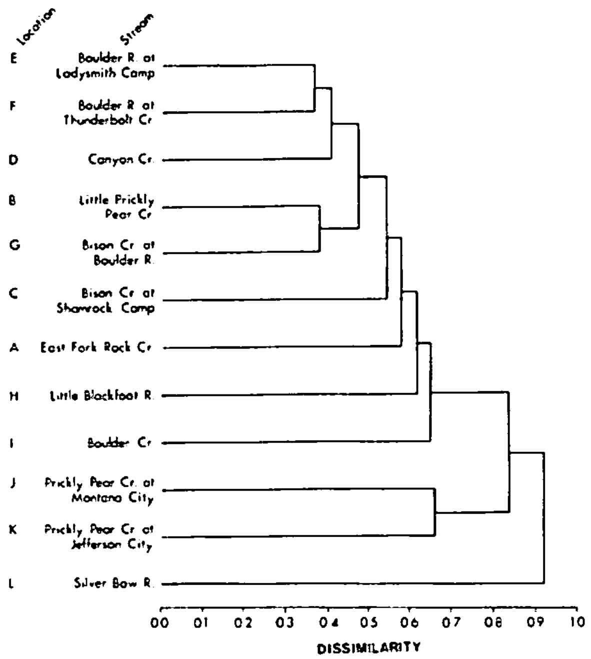

Figure 4. Dissimilarity of samples as shown by cluster analysis. Sites *J*, *K*, and *L* are the impacted sites.

of the relative condition of the biota at that time. Gammon and Reidy (1981) have shown that, given proper ecological measures and a thorough sampling of available habitats, a single fish sample can usually rank comparable sites the same regardless of seasonal or annual variations. Although the rankings would be unlikely to change, periods of high runoff would likely produce greater differences between impacted and control sites because of the increased leaching of metals from the tailings along the impacted streams.

Not surprisingly, the presence of trout at a site is insufficient evidence for establishing ecosystem health or for identifying satisfactory habitat. The quality of a salmonid fishery is increased by larger and more abundant salmonids. All control sites but Boulder Creek at Maxville had significantly higher salmonid biomasses than impacted sites. This, and the increase in relative abundance of suckers at Prickly Pear Creek near Montana City, indicated a reduction in the quality of the sport fishery at the impact sites. The abundance of macroinvertebrate taxa in comparison with other streams is also a more meaningful measure of integrity than the presence of trout. For example, numbers and proportions of macroinvertebrate genera and families indicated considerable difference in community structure between the impacted and control sites. Such differences in community structure and abundance of key species demonstrate the weakness of water quality standards that can be satisfied by the existence of a few trout in Prickly Pear Creek or any other stream.

Although not all community measures showed significant differences between impacted and control sites, there was evidence for communitywide degradation at Silver Bow River and both sites on Prickly Pear Creek. The cluster and principal components analyses of the taxa indicated that the composition of the fish and macroinvertebrate assemblages between the impacted and control sites differed considerably (Figures 3 and 4). As in many field studies, it is difficult to separate the causes of the differences. Certainly zinc concentrations exceeded criteria at Silver Bow and Prickly Pear at Jefferson City. But mean substrate size was significantly smaller and woody riparian vegetation was significantly less at both sites as a result of sand washed from the tailings piles, channel modifications for roads, and, at Prickly Pear Creek at Jefferson City, hydraulic gold mining. The changes in physical habitat may have been as important as toxic levels of metals in causing degradation of the stream biota. When physical and chemical habitat are degraded by mining activities, as at Silver Bow and Prickly Pear at Jefferson City, mitigation of only one factor is unlikely to significantly improve the biota.

The degraded physical habitat at Montana City, below the recovery zone on Prickly Pear Creek, and the absence of suitable upstream control sites exemplify the problem of depending on only intensive postimpact or upstream-downstream studies to document impacts of point sources. Such limited comparisons can be misleading whenever stream size changes considerably or when the entire stream section, including the site being studied, is degraded in ways other than the one being examined.

Greater differences in topography and vegetation among watersheds of the larger streams in this study may account for the wider confidence intervals associated with the data sets for those larger streams (b and c in Figure 2 and streams A, H, and I in Figure 4). Nonetheless, cluster and principal components analyses indicate that the differences in the fish and macroinvertebrate assemblages among the nine control streams were less than those between the metal-impacted and recovery sites of Prickly Pear Creek.

The relatively close grouping of the control streams demonstrates that those streams had relatively similar fish and macroinvertebrate assemblages when compared with the impacted sites (Figures 3 and 4). This is an encouraging result although it is based on limited data, because, if similar biotic communities occur in streams with similar habitats, if similar habitats occur in similar-sized streams in similar watersheds, and if similar watersheds can be found and classified through the use of maps, then stream ecologists are provided with a unified

Table 3. Environmental features of 12 stream sites.

Stream	Hardness (mg/l $CaCO_3$)	Cu (μg/l)	Zn (μg/l)	C/N	Watershed area (km^2)	Runoff (cm/yr)	Discharge (m^3/yr)	Peak velocity (cm/s)
a) Prickly Pear–Jeff. City[a]	168	<5	850[d]	11	118	15	177	85
Canyon[b]	120	10.5[c]	40	9	108	15	162	65
Bison–Shamrock Camp.[b]	72	10.5[c]	20	12.5	97	15	146	85
Boulder–Thunderbolt Cr.[b]	48	<5	<10	16.6	82	15	123	73
b) Prickly Pear–Mont. City[a]	168	<5	330[c]	50	190	15	285	119
Bison–Boulder Rv.[b]	48	<5	630[c]	14.3	136	15	204	95
Boulder–Ladysmith Camp.[b]	72	<5	<10	11	169	15	254	97
L. Prickly Pear[b]	240	<5	<10	11	265	12	318	77
c) Silver Bow[a]	936	50[c]	1700[d]	7.7	204	15	306	87
Boulder Cr.–Maxville[b]	96	<5	20	16.6	93	23	214	104
L. Blackfoot[b]	96	<5	20	16.6	97	20	194	83
East Fork Rock[b]	216	<5	20	12.5	110	20	220	106

[a] Impacted site.

[b] Control site.

[c] Exceeds national chronic criterion (US Environmental Protection Agency 1980a and b).

[d] Exceeds national acute criterion (US Environmental Protection Agency 1980b).

empirical and theoretical framework that is potentially more powerful than the stream continuum concept (Vannote and others 1980) for organizing their knowledge.

There are several ways of classifying stream systems to provide a regional perspective. As reviewed by Hawkes (1975), most stream classifications are based on similarities in stream habitat, fauna, or both, with no consideration of the watershed. Such classifications, like that suggested by Pennak (1971), required large amounts of data that are difficult to synthesize into meaningful classes of stream ecosystems because of the inherent spatial and temporal variability of randomly collected field data. Another popular approach is to classify streams on the basis of a stream continuum or stream size (Vannote and others 1978), with stream order (Strahler 1957) being used as an estimate of size. Hughes and Omernik (1983), however, logically and empirically demonstrated that watershed area and discharge are more accurate measures than stream order of stream size, and Minshall and others (1983) emphasized the necessity of embedding the stream continuum in a macroenvironmental framework. This was done to some degree by Platts (1974, 1978, and 1979) and Pflieger (1971 and 1981), who related the distribution and abundance of fish species and habitat features to watershed geomorphology and stream size.

A possible alternative is to identify similar streams using a watershed classification based on available maps of several factors believed to determine the major characteristics of aquatic ecosystems, such as climate, surficial geology, land-surface form, land use, soil, and potential natural vegetation. It is assumed in this approach that similar watersheds produce similar streams, that these watersheds occur in definable ecological regions and that these ecoregions can be determined most reliably by examining several regional characteristics rather than one or two. Such ecoregions facilitate perception of patterns of similarities and differences in watershed characteristics, and therefore in the potential ecological conditions of streams.

In turn, patterns made evident by ecoregions facilitate (a) an understanding of general land–water relationships within different parts of an ecoregion, (b) development of regional water quality criteria versus an unworkable number of site-specific criteria or weak or inflexible national criteria, (c) the selection of control streams, demonstration sites or field models that are representative of many other ecosystems in an ecoregion, (d) rational extrapolation from previous site-specific studies, (e) the prediction of typical and potential conditions of aquatic ecosystems, and (f) the prediction of the results of changing land use or pollution levels.

Conclusions

The typical upstream–downstream or intensive post-impact approach for assessing impacts on a stream is of little use where the entire stream is heavily impacted by other point or diffuse sources of pollution, channel modifications, or removal of riparian forests, or where the impacted and potential control sites differ considerably in flow or morphology for natural reasons. In such cases, it is useful for managers of aquatic ecosystems to be able to estimate potential ecological conditions and attainable uses from a regional perspective using regional control sites.

In western Montana, a regional perspective facilitated selection of control sites on several streams based on similarities in the watershed characteristics and sizes of the control and impacted streams. This allowed selection of less-impacted control sites than those found elsewhere on the impacted streams, and these control sites allowed the estimation of the potential habitat and biotic conditions in the impacted sites if they were unaffected by mining activities.

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Appendix. Taxa collected in one sample from 12 southwestern Montana stream sites; macroinvertebrates are given as no./m^2 and fish as no./m^2 and g/m^2 in italics, * = <0.005/m^2.

Taxon	Prickly Pear Jeff. City	Canyon	Bison-Shamrock	Boulder-Thunderbolt	Prickly Pear-Montana City	Bison-Boulder	Boulder-Ladysmith	L. Prickly Pear	Silver Bow	Boulder Cr.	L. Blackfoot	E.F. Rock
Dugesia		1								1		
Nematomorpha		1										
Hirudinea												4
Lumbricidae												1
Naididae			1			16		10	1	10		2
Annelida sp. 4												48
Ameletus						1	4				3	
Baetis	10	18	1	2		2	18	146		33	2	2
Cinygmula											1	1
Epeorus deceptius				1								
E. grandis										11		
Epeorus sp. 3										1		
Ephemerella coloradensis		4		1								
E. doddsi		6								40	2	
E. drunnella										4		
E. serratella		2	2	4		5	5			3	1	9
E. spinifera		1	1			16	2	11		1	3	5
Heptagenia		21		1			26				10	
Paraleptophlebia		1	8	5		2	64	2				
Rhithrogena		53	1	8		19	3	81		34	3	
Alloperla		5	5	5		34	18	182		5	10	
Arcynopteryx						3	1			12	2	
Brachyptera										1		
Calineuria	1	3	1	1								
Hesperoperla		2				4	5	4				2
Perlodidae sp.				1								
Pteronarcella	1	1				14		18				
Pteronarcys californica								3				
Skwala		1	1	2		20		3				1
Zapada cinctipes		52					2			9		
Zapada sp. 2				5	1	8				6	1	
Apatania		3		3			3				3	8
Arctopsyche	58	39	1	6		5	7	14		3		27
Brachycentrus	49	1		12	6	20	17	190			19	828
Dolophilodes										12		
Ecclisomyia											8	22
Glossosoma		12		2		3	4	126		16		87
Halesochila											1	
Hydropsyche	1	68	2	1		60	52	95			2	3
Hydroptila							6					
Lepidostoma quercina			5					1				
L. unicolor							2					
Lepidostoma sp. 3						1						
Limnephilidae sp. 1						1						1
Limnephilidae sp. 2						2						
Micrasema	21	2	69	6		63	67	300		3	8	2

Appendix (continued).

Taxon	Prickly Pear Jeff. City	Canyon	Bison-Shamrock	Boulder-Thunderbolt	Prickly Pear-Montana City	Bison-Boulder	Boulder-Ladysmith	L. Prickly Pear	Silver Bow	Boulder Cr.	L. Blackfoot	E.F. Rock
Neothremma					2							
Oecetis								8				2
Parapsyche										8		
Rhyacophila acropeles		22				3	1			8		2
R. sibirica										24	2	
Rhyacophila sp. 3										9		
Dytiscidae							2					
Haliplidae				1								
Heterlimnius	2	2	1	4		9	5	6		10	19	12
Lara		1										
Optioservus		10	1	5		10		12				3
Zaitzevia			2									
Antocha	6	1				1	2	57				7
Hexatoma sp. 1		2	19	17		2	5	1			3	7
Hexatoma sp. 2								7				
Tipula sp. 1			4					1			1	2
Tipula sp. 2								3				5
Tipula sp. 3											16	
Pericoma sp. 1		10	7	97			72		1	1	66	5
Pericoma sp. 2		4		8		1	6	1			5	
Bezzia			2									
Simulium		49					3	44				
Cricotopus			20			6						25
Orthocladiinae sp. 1	10		1	4			10	16	17			8
Orthocladiinae sp. 2	7			2			2			1		2
Orthocladiinae sp. 3	1						2					1
Orthocladiinae sp. 4			5				14	3		1		4
Orthocladiinae sp. 5			1				1	2				6
Rheotanytarsus			1	1		7	5					1
Tanypodinae sp. 1						1						
Tanytarsus												2
Bittacomorpha												2
Atherix	7				2	4						
Glutops		5										
Hemerodromia										1		
Empididae sp. 3						1						
Limnophora	2								1			
Bulminidae sp. 1												1
Lymnaea								37				5
Physa								39				
Pisidium								13				50
Planorbidae sp. 1								1				4
Salmo clarki											* *0.03*	0.03 *2.0*
S. gairdneri		0.04 *1.4*	0.09 *3.6*	0.03 *2.2*	0.01 *1.2*	0.04 *2.4*	0.05 *2.1*	0.04 *3.8*				
S. trutta					**0.02*			0.02 *7.1*		* *0.4*	0.01 *0.5*	
Salvelinus fontinalis	0.05 *1.5*	0.01 *1.2*	* *0.3*	0.09 *6.1*		0.01 *0.6*	0.06 *3.8*				* *.2*	
Prosopium williamsoni			0.01 *2.4*				* *0.8*				0.02 *5.9*	0.01 *1.6*
Catostomus catostomus					0.01 *5.8*							
Catostomus commersoni					* *0.7*							
Cottus bairdi	0.04 *0.2*	0.30 *2.3*	0.44 *5.0*	0.33 *4.4*	0.04 *0.6*	0.66 *7.0*	0.41 *3.5*	1.29 *17.0*				
Cottus cognathus										0.01 *0.1*	0.29 *1.8*	0.30 *5.5*